

## **Decline in radiation hardened microcircuit infrastructure**

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# Acronyms

| Acronym | Definition  |
|---------|---|
| ASIC    | Application Specific Integrated Circuit   |
| CDH     | Central DuPage Hospital Proton Facility, Chicago Illinois                                       |
| CNL     | Crocker Nuclear Lab   |
| COTS    | Commercial Off The Shelf  |
| ESA     | European Space Agency   |
| FPGA    | Field Programmable Gate Array   |
| GSFC    | Goddard Space Flight Center   |
| HUPTI   | Hampton University Proton Therapy Institute   |
| IBM     | International Business Machines   |
| IEEE    | Institute of Electrical and Electronics Engineers   |
| IUCF    | Indiana University Cyclotron Facility   |
| ITAR    | International Traffic in Arms Regulations   |
| LBNL    | Lawrence Berkeley National Laboratories   |
| LLUMC   | James M. Slater Proton Treatment and Research Center at Loma<br>Linda University Medical Center |
| MGH     | Massachusetts General Hospital  |
| NASA    | National Aeronautics and Space Administration   |
| NEPP    | NASA Electronic Parts and Packaging   |
| NSREC   | Nuclear and Space Radiation Effects Conference  |
| NSRL    | NASA Space Radiation Laboratory   |
| ProCure | ProCure Center, Warrenville, Illinois   |
| SEE     | Single Event Effect   |
| SEU     | Single Event Upset  |
| TRIUMF  | Tri-University Meson Facility   |
| UCD     | University of California at Davis   |

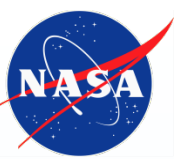


# Abstract

- **Two areas of radiation hardened microcircuit infrastructure will be discussed:**
  - The availability and performance of radiation hardened microcircuits, and,
  - The access to radiation test facilities primarily for proton single event effects (SEE) testing.
- **Other areas not discussed, but are a concern include:**
  - The challenge for maintaining radiation effects tool access for assurance purposes, and,
  - The access to radiation test facilities primarily for heavy ion single event effects (SEE) testing.
- **Status and implications will be discussed for each area.**



# **U.S. RADIATION HARDENED MICROCIRCUITS**



# **Radiation Hardened Microcircuits - Foundries**

- **Well known decline in number of U.S. manufacturers of radiation hardened microcircuits:**
  - **From 20+ in 1990 to a handful in 2015.**
- **Many of the existing suppliers utilize a “foundryless” model where they are either:**
  - **A design house using a 3<sup>rd</sup> party fabrication facility, or,**
  - **Upscreen parts while adding radiation mitigation approaches (shielding, supervisory control, etc...)**
- **Changes to ITAR (U.S. State Department to Commerce) should ease access to these products for non-U.S. entities not on restricted list.**



# Foundries - Current Concern

- **The cost of operating a dedicated state-of-the-art foundry is in the \$Billions.**
  - Using a commercial fabrication facility (like IBM) as front end for silicon die with radiation hardened library development (intellectual property, IP) and a Military/Aerospace vendor as the back end (packaging, test) has been the working plan.
  - This is similar to European Space Agency (ESA) approach with ST Microelectronics, for example.
- **Many future radiation hardened standard product and Application Specific Integrated Circuit (ASIC) plans were based on the use of the former IBM foundry that is now GlobalFoundries (non-U.S. owned).**
  - While the use of non-U.S. foundries/products is common for NASA missions, the U.S. government, in general, is concerned over access to a U.S. foundry.
- **U.S. Government is reviewing options at this time.**
  - NASA may be affected indirectly for future standard product access, but does not develop many ASICs requiring advanced technology nodes.



# **Radiation Hardened Microelectronics – More COTS?**

- **The underlying challenge:**
  - **Traditional radiation hardened electronics are multiple technology generations behind the commercial alternatives:**
    - e.g., radiation hardened field programmable gate array (FPGA): 65nm feature size
    - Current state-of-the-art commercial FPGA: 20nm feature size. This is 3-4 generations more modern.
  - **As technology has scaled, the power and volume versus performance metrics are improved – faster, smaller, more highly integrated, lower power.**
- **While NASA's been a user of commercial parts since the 1970's, these modern, very complex parts may require large amounts of additional mitigation for radiation sensitivities and evaluated for reliability challenges.**
  - **Modern system design mixes radiation hardened devices (“failsafe safing”) with high-performing COTS devices.**



# ALL ABOUT PROTONS



# Indiana University Cyclotron Facility (IUCF) Closure

- IUCF has been the most used higher energy proton test facility for most of the U.S. space industry (electronics).
  - It is primarily a medical facility that NASA and others have supported to develop a parallel capability for proton testing of electronics.
    - *~2000+ hours of use per year for electronics testing*
  - IUCF closed to the Space Community Usage on Oct 31, 2014.
  - High energy Proton Test (>200 MeV) is Critical to Space Community.
- Ad hoc U.S. government team formed to investigate options.
  - Existing proton SEE test facilities (North America).
  - Explore access to newer proton cancer therapy sites.
- Study began in 2014-Oct.



# Existing North American Proton Facilities

- **Tri-University Meson Facility (TRIUMF) – Vancouver, Canada**
  - Challenges with “border crossing,” limited “cycles” of availability
    - *TRIUMF is working w/ US State Department for easier access and hardware transfer*
- **Massachusetts General Hospital (MGH) Francis H. Burr Proton Therapy Center (additional access limited beyond current beam amounts),**
- **University of California at Davis (UCD) Crocker Nuclear Lab (CNL),**
  - Lower prime energy (63 MeV) does not meet all test requirements
- **Lawrence Berkeley National Laboratories (LBNL) – (50 MeV) has similar technical challenges as CNL, and,**
- **Loma Linda University Medical Center (LLUMC) and NASA Space Radiation Laboratory (NSRL) – have pulsed beam structures and other technical considerations.**



# Ad Hoc “Team” Plan/Status – Proton Therapy Sites

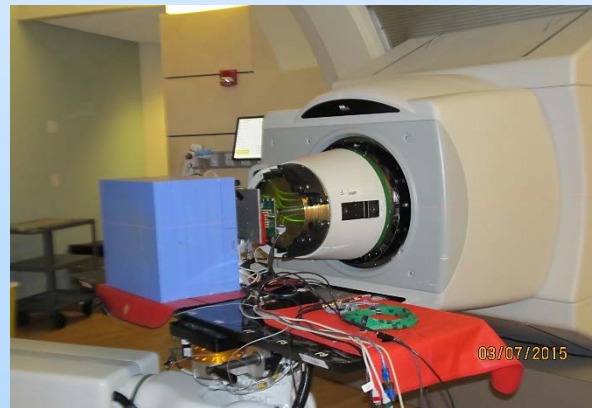
- ✓ **Contact facilities (focus on cyclotrons)**
- ✓ **Site visit to determine interest**
  - Technical
  - Access
  - Business case
- ☐ **Beta/shakeout tests at interested sites to determine usability**
  - ☐ Underway
- ☐ **Work logistics of access**
  - ☐ Underway
- **Determine guidelines for usage of these sites**
  - Goal is to discuss at IEEE Nuclear and Space Radiation Effects Conference in Boston, MA in July.
- **Recommendations for modifications and longer term access.**
  - TBD

**Assumption:** Facilities will have available 300-500 hours/year each (weekends).  
Multiple facilities required to replace IUCF in the near term.



# Challenges Identified with Using Proton Therapy Facilities

- **Technical**
  - Beam structure and delivery are mostly different than we are used to. *This is the largest technical concern.*
  - Independent dosimetry required for SEE testing – flux, fluence and uniformity.
  - Beam intensity control: translation between SEE test parameters and tumor delivery.
  - Beam stops required (therapy “stops” beam in patient).
  - Radiation dose limits may impact some higher fluence tests.
  - Remote-controlled movement of test article mounting stage may not exist at all sites – time hindrance.
- **Logistics**
  - Access
  - Scheduling
  - Cost



*Testing at Cadence Health Proton Center,  
Warrenville, IL USA*



# Background: Proton Beam Delivery

- There are two types of facilities being used for proton therapy:
  - Cyclotrons, and,
  - Synchrotrons.
- In addition, there are three types of beam delivery methods.
  - Scatter,
  - Wobble/uniform scan, and,
  - Pencil beam scan.
- *IUCF was a **cyclotron** and utilized a **scatter** beam delivery system.*
  - *Other options require thought and consideration for possible use.*



# Proton Facility Status

|                     | Facility  | Location                     | Visit | Beam Attributes*         | User friendly** | Hourly Rate | Invest. required | Annual Hours             | Current Avail. | Short term Avail. | Long term Avail. | Beta Test |
|---------------------|---|------------------------------|-------|--------------------------|-----------------|-------------|------------------|--------------------------|----------------|-------------------|------------------|-----------|
| Future Facilities   | Cadence Health (CDH) Proton Facility - ProCure  | Warrenville, IL              | Y     | Acceptable (cyclotron)   | N/A             | TBD         | Yes \$ TBD       | 500                      | No             | Maybe             | Maybe            | Mar 7     |
|                     | Hampton University Proton Therapy Institute (HUPTI)   | Hampton, VA                  | Y     | Acceptable (cyclotron)   | N/A             | TBD         | Yes \$ TBD       | 350                      | No             | Maybe             | Maybe            | TBD       |
|                     | Provision Center for Proton Therapy   | Knoxville, TN                | Y     | Acceptable (cyclotron)   | N/A             | TBD         | Yes \$ TBD       | 500                      | No             | No                | Maybe            | TBD       |
|                     | Seattle Cancer Care Alliance Proton Therapy - ProCure                                       | Seattle, WA                  | Y     | Acceptable (cyclotron)   | N/A             | TBD         | Yes \$ TBD       | 500                      | No             | Maybe             | Maybe            | Yes       |
|                     | University of Florida Proton Therapy Institute  | Jacksonville, FL             | Y     | Acceptable (cyclotron)   | N/A             | TBD         | Yes \$ TBD       | 500                      | No             | No                | Maybe            | TBD       |
|                     | University of Maryland Proton Treatment Center  | Baltimore, MD                | Y     | Acceptable (cyclotron)   | N/A             | TBD         | Yes \$ TBD       | 500                      | No             | No                | Maybe            | TBD       |
|                     | Scripps Proton Therapy Center   | La Jolla, CA                 | Y     | Acceptable (cyclotron)   | N/A             | TBD         | Yes \$ TBD       | 500                      | No             | Maybe             | Maybe            | May 1-2   |
|                     | OKC ProCure Proton Therapy Center   | OKC, OK                      | Y     | Acceptable (cyclotron)   | N/A             | TBD         | Yes \$ TBD       | 500                      | No             | Maybe             | Maybe            | May-June  |
|                     | Mayo Foundation   | Rochester, MN<br>Phoenix, AZ | N     | TBD (synchrotron)        | TBD             | TBD         | TBD              | TBD                      | No             | No                | TBD              | TBD       |
| Existing Facilities | Tri-University Meson Facility (TRIUMF)  | Vancouver, CAN               | N     | Acceptable (cyclotron)   | Yes             | \$750       | No               | 4x/year                  | Yes            | Yes               | Yes              | N/A       |
|                     | Slater Proton Treatment and Research Center at Loma Linda University Medical Center (LLUMC) | Loma Linda, CA               | Y     | Acceptable (synchrotron) | Yes             | \$1,000     | No               | 1000                     | Yes            | Yes               | Yes              | N/A       |
|                     | Mass General Francis H. Burr Proton Therapy   | Boston, MA                   | N     | Acceptable (cyclotron)   | Yes             | \$1,000     | No               | < 800 hours, at capacity | Yes            | Yes               | Yes              | N/A       |
|                     | NASA Space Radiation Lab (NSRL)   | Brookhaven, NY               | Y     | Acceptable (synchrotron) | Yes             | \$4,700     | No               | > 1000 hours             | Yes            | Yes               | Yes              | N/A       |
|                     | Indiana University Cyclotron Facility   | Bloomington, IN              | N/A   | Reference                | Yes             | \$820       | N/A              | 2000 hours               | No             | No                | No               | N/A       |

\*Beam size, dosimetry, flux, fluence, uniformity; \*\*location, safety training, regulations, scheduling, payment, hazardous material handling, shipping, contracts, ITAR, etc...

European Space Research Institute (ESRIN) Trilateral Face-to-face (F2F) Working Group Meeting, Frascati, Italy, May 22, 2015.



# Proton Takeaway Chart

- **Rules of thumb**
  - **All proton cancer therapy sites are usable for static tests, parts that are fairly proton-SEU tolerant, and destructive tests.**
    - **Cyclotron, synchrotron**
    - **Any of the beam delivery modes (scatter or scan)**
  - **Timing dependent tests (dynamic operations) especially on very proton sensitive devices require careful thought for using other than an IUCF-like beam (a cyclotron with a scatter mode).**
    - **Further work is needed to evaluate useful nature of scan beam delivery.**
  - **Guideline development will be a critical deliverable by this team.**
    - **Expect to have a version available at IEEE Nuclear and Space Radiation Effects Conference**
      - **Boston, MA. USA – July 13-17, 2015.**



# Protons – The Future

- **Access/contracts/technical logistic “headaches” for cancer centers must be minimized to allow widest use for radiation effects research.**
  - **We are NOT their prime customer.**
  - **Long-term access hinges on three items:**
    - **Minimum invasiveness of our community on cancer therapy sites (technical, logistics),**
    - **Business model (for cancer therapy sites), and,**
    - **Medical usage not expanding to use “spare time” – insurance and doctor access are current limits, but may be changing.**



# QUESTIONS?